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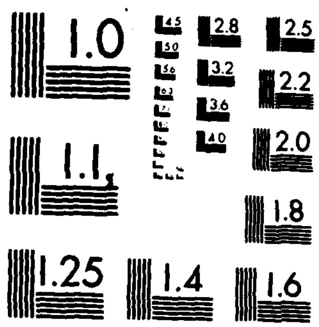

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THE SHORELINE VEGETATION OF LAKE SAKAKAWEA, A MAN-MADE FLUCTUATING WATER LEVEL RESERVOIR OF THE UPPER MISSOURI RIVER BASIN

FINAL REPORT

June 1, 1973

by

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and

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ABSTRACT

Lake Sakakawea is a huge man-made fluctuating water level lake in the upper Missouri River Basin. Lake Audubon is a smaller non-fluctuating reservoir adjoining Lake Sakakawea and also formed by the Garrison dam across the Missouri. These lakes are found in the glaciated portion of western North Dakota. North Dakota has a semiarid continental climate and the climax vegetation is Agropyron-Stipa mixed grass prairie.

During the summer of 1971, 50 study sites were established on ~~these~~ LAKE SAKAKAWEA & LAKE AUDUBON lakes to study the vascular plants growing along the shoreline. These sites were permanently marked, and the vegetation was analyzed in 2 x 5 dm. plots along a transect across the shore at each site. On Lake Sakakawea, the fluctuating water level lake, three zones are described, zone inundated every year, a zone inundated 3 years ago, and a zone above the highest water mark. The plant communities found and described in these zones are: Zone 1- a Rumex crispus (Dock)-Polygonum persicaria ephemeral annual weed community, and a Phalaris arundinacea (Reed Canarygrass) community; Zone 2- the same Phalaris arundinacea community is found here along with an Agropyron smithii (Western Wheatgrass)-Hordeum jubatum (Squirreltail grass) weedy community; Zone 3- in the undisturbed areas there was an Agropyron smithii-Stipa comata (Green Needlegrass) community and in certain disturbed areas we found 2 closed communities, a Bromus inermis (Smooth brome) community and an Agropyron cristatum (Crested wheatgrass) community. But the most common community in this area was an Agropyron repen (Quackgrass)-Poa pratensis (Kent. Bluegrass) community. Around Lake Audubon, the non-fluctuating reservoir, there are also three zones, slightly different from those around Lake Sakakawea. They are an open water zone, a

wet shoreline zone and an upland zone. Very little vegetation is found, curiously, in the open water zone. The wet shoreline community is dominated by emergent aquatics, and the upland is similar to the upland zone around the other lake.

Results of soils analyses were similar on the 50 sites as a result of soils developing on nearly uniform parent material under nearly uniform climatic conditions. The soils are mostly loamy Chestnuts.

Multiple regression analyses of various soil factors on the coverage values of the important species indicated little dependance of vegetation on soil texture, nitrogen, organic matter, and slope. Wave action and water level fluctuation are less easy to quantify but have highly important influence on the shoreline vegetation.

Diversity of vegetation in the 3 zones is discussed. Vegetation changes during the one year period and successional trends and possibilities are described and beneficial water management policies are discussed along with the need for further studies and possible plantings.

INTRODUCTION

Lake Sakakawea is located in western North Dakota (see Fig. 1) near the geological center of North America. Western North Dakota has a typical continental climate. In our study region average monthly temperatures range from a low of -13°C in January to high of 21°C in July, and annual average precipitation ranges from 37 cm at Williston at the western end of the lake to 40 cm at Garrison at the eastern end. Climatic data for both these locations are found in Table 1. Additionally, the seasonal distribution of precipitation is important to the vegetation of the region with about 75% of the total received from April through September.

The geological history of that portion of North Dakota in which Lake Sakakawea is found is relatively simple. The entire area is underlain by the Tertiary Tongue River formation of the Fort Union group (Leonard 1930). The great bulk of these 300 m deep sediments are lacustrine in origin. Numerous lignite beds often exposed by erosion along the shore are evidence of the presence of swamps. The entire region was glaciated during the Kansan Period and the Fort Union formation was overlain with a relatively thin deposit of glacial till. At this time the course of the Little Missouri River was permanently altered, increasing the grade which in turn resulted in much erosion creating the 'badland' topography. The glaciation occurred during early Pleistocene and south and east of the lake most of the glacial ground moraine has eroded away, the Tertiary beds exposed, and a dendritic drainage pattern restored. But around Lake Sakakawea glacial till is predominant all around the lake

except for a small area where it has been eroded by the Little Missouri River.

The upland climax vegetation throughout our region is, according to Küchler (1964), an *Agropyron-Stipa* mixed grass climax. A map more detailed than that of Kuchler would show this general area to be a mosaic of distinctly different communities varying from one place to another in response to a complex of environmental factors. In more mesic sites certain tall grasses such as big bluestem *Andropogon gerardi* and sand reedgrass *Calamovilfa longifolia* predominate; and increase in wet years. In more xeric sites other species such as blue grama *Bouteloua gracilis* predominate and tend to increase in dry years. Several woody communities and clones complete the mosaic. A detailed description of the steppe vegetation of western North Dakota is given by Hanson and Whitman (1938) and some of the woody communities are described by Nelson (1961). Man's activities, primarily farming and grazing of cattle and sheep, have altered the vegetation patterns, destroyed many communities, and promoted an increase in weedy species.

A lake can be defined as a body of water large enough that wave action prevents the permanent establishment of macro vegetation along a narrow strip of shoreline, while a pond, is defined as a smaller body of water in which there is negligible wave action so that the shoreline vegetation can become permanently established (Daubenmire, 1968). By the definition given Lake Sakakawea is a lake, but some embayments around the perimeter are sufficiently protected that they may be considered ecologically as ponds.

Figure 1. The location of study sites on Lake Sakakawea, and Lake Audubon. The inset shows the location of Lake Sakakawea in North Dakota.

LOCATION OF STUDY SITES ON LAKE SAKAKAWEA

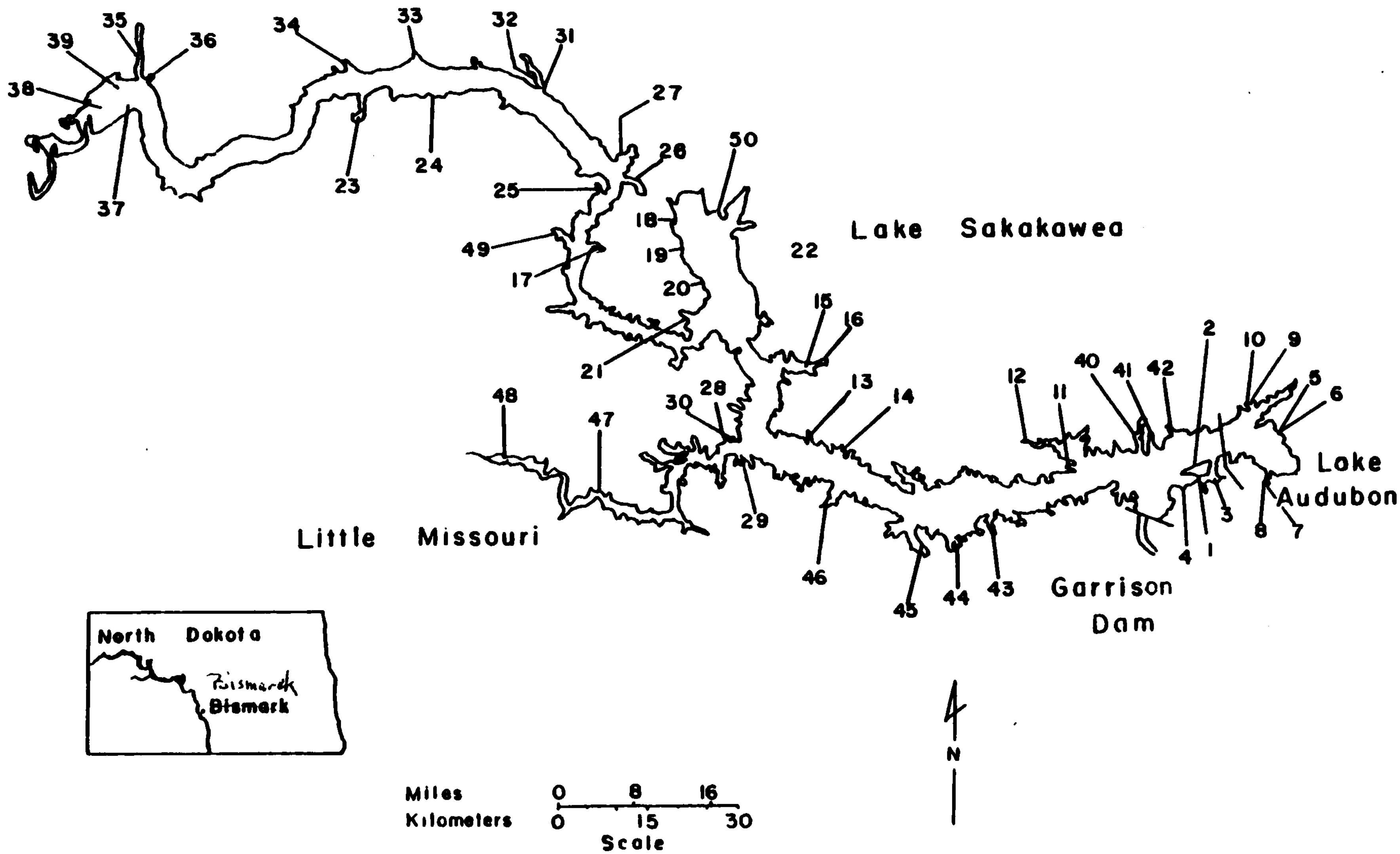


Table 1. Climatic data from Williston, N. D., at the western end and Garrison, N. D., at the eastern end of Lake Sakakawea. P is average precipitation in cm. and T is average temperature in °C.[a]

	Williston, N. D.		Garrison, N. D.	
Month	P	T	P	T
January	1.2	-12.1	1.5	-13.0
February	1.2	-10.2	1.4	-10.8
March	1.9	-3.0	1.9	-4.6
April	2.7	6.0	3.2	5.3
May	4.2	12.4	5.2	12.2
June	9.1	17.0	8.8	16.9
July	5.4	21.4	6.0	21.1
August	3.6	19.8	4.6	19.6
September	3.1	13.9	3.2	14.0
October	2.0	7.4	2.0	7.3
November	1.5	-2.0	1.6	-2.8
December	1.4	-9.0	1.1	-9.4
Annual	37.2	5.1	40.5	4.7

[a]U. S. Dept. of Commerce, Weather Bureau. 1959. Climatography of the United States No. 60-32, North Dakota, 16p.

Like all the other reservoirs of the Missouri River basin Lake Sakakawea is long and narrow. It is 323 km. long and has 2419 km. of shore. The average width is 5 km. Lake Sakakawea was formed by the closure of Garrison dam in 1953. In terms of water-holding capacity and surface area it is the largest of the Missouri River mainstem ~~dams~~ lakes. With a capacity of 30.2 billion m^3 of water (Benson, 1968) it has covered many square km. of farmland and wildlife habitat. Lake Sakakawea was at full pool by 1957. The water levels for the six most recent years are graphed in Fig. 2. The water level generally drops during the late growing season to reach a low during February or March. The water rises some until the first of June when it rises sharply to its highest point about late July or early August, sometimes later (1968). For the remainder of the year the water level recedes gradually. During the first half of the growing season, or until about the middle of July the plants which are becoming established or resuming growth are gradually inundated. It should also be noted that, asthetically, this is an ideal policy, for there is never very much muddy shoreline exposed during the summer when the lake is most often visited. Because the wind often blows, and because Lake Sakakawea is huge, wave action has eroded headlands along the shore forming large cliffs. The finer particles are more easily eroded away leaving a shoreline "armoured" with rocks from the glacial till, and inlets are cut off by littorally deposited sand, silt, and clay. In lakes which have a constant water level a terrace is cut at the point where the water meets the shore and the eroded material is built into a shelf extending out into the water

(Pearsall, 1918). In lakes like Lake Sakakawea in which the water fluctuates greatly (Fig. 2) the cutting effect is moved vertically along the shoreline with the water level leaving a bare eroded apron. In the upper reaches of the reservoir, and in areas where the tributaries enter the lake, deltas are built up forming large unsightly sand or mud bars.

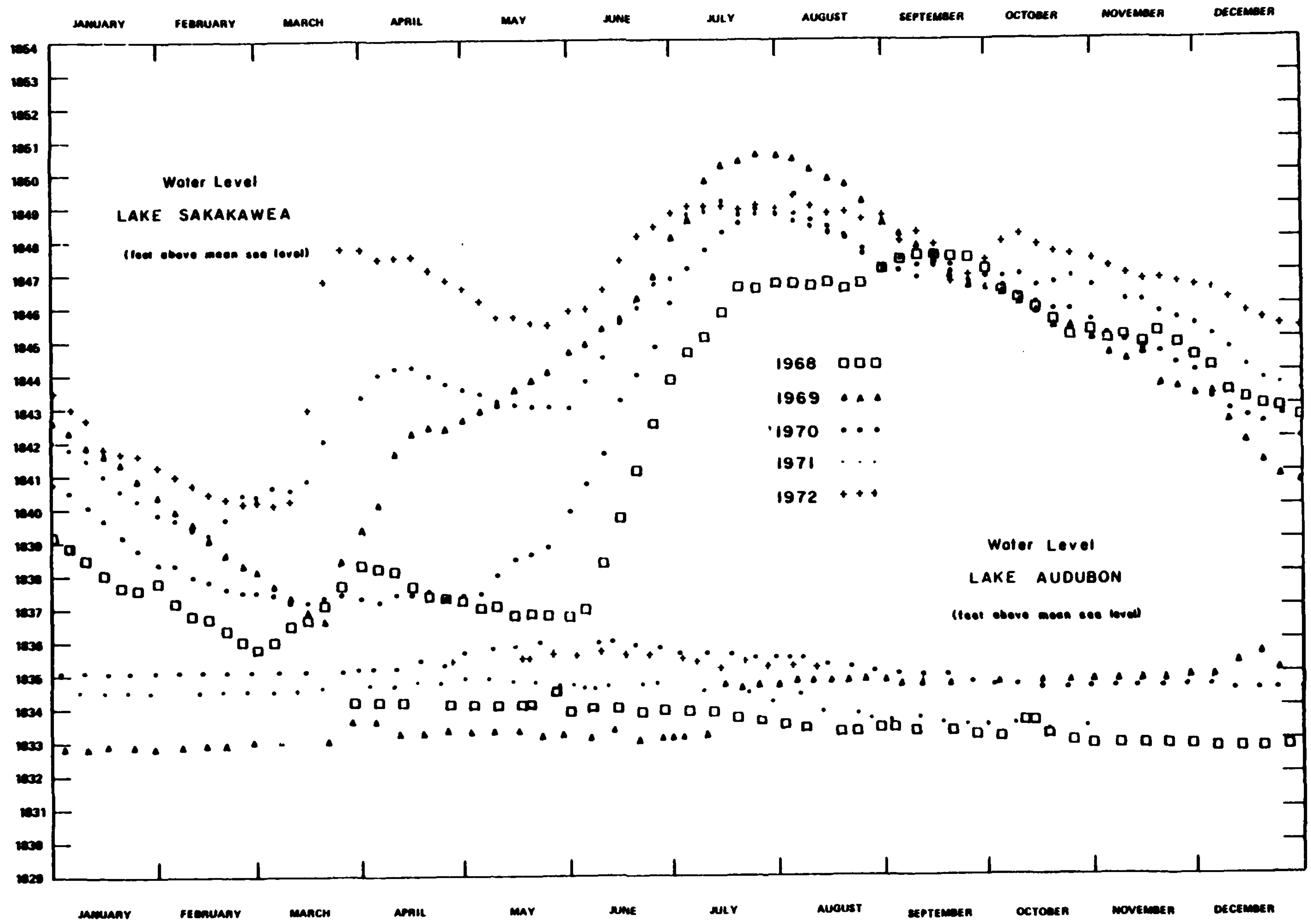
Lake Audubon is a small subimpoundment of Lake Sakakawea (Fig. 1). It was formed as a result of the relocation of U.S. Highway 83 and the Soo Line Railroad 13 km northwest of Coleharbor, North Dakota, prior to the closure of Garrison Dam. In recent years water from Lake Sakakawea has been transferred into Lake Audubon to maintain a 5 m head differential between the two impoundments. (Mr. R. G. Burnett, personal correspondence).

Lake Audubon is much smaller and shallower than Lake Sakakawea, but still large enough to be considered a lake as defined above. The main difference between the two lakes is that the water level in Lake Audubon has been maintained at a nearly constant level, making this lake a suitable control on which to check the effect of water fluctuations on shoreline vegetation. The water level of Lake Audubon is also shown in Fig. 2.

It has long been observed that man-made fluctuating water level reservoirs are not conducive to the successful establishment of shoreline vegetation; thus the objectives of our study were as follows:

1. To quantitatively describe the vegetation which does occur along the shoreline of Lake Sakakawea, noting

Figure 2. Water level fluctuations in Lake Sakakawea and Lake Audubon between 1968 and 1972.



JANUARY
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1832
1831
1830
1829
Water Level
LAKE SAKAKAWEA
(feet above mean sea level)
1968
1969
1970
1971
1972
Water Level
LAKE AUDUBON
(feet above mean sea level)

ephemeral or permanent nature of the vegetation.

2. To quantify some of environmental factors influencing this vegetation and to correlate these data with the distribution or importance of these species.
3. To note plant successional trends where possible, and to describe these trends in relation to water management policy.
4. To compare the vegetation of Lake Sakakawea and Lake Audubon shorelines to describe possible effects of water fluctuation on vegetation.
5. To discover shoreline species preadapted to maintain themselves in the face of the unusual environmental conditions imposed on the terrestrial habitats contacting the reservoir.

METHODS

Field Studies. Our study was initiated in July, 1971. We made extensive reconnaisance trips around the lake becoming familiar with the local roads and access areas, and collecting plants representative of the flora of the region. Plant collections have been made throughout the duration of our study, and voucher specimens are deposited in the University of South Dakota herbarium, Vermillion. It became apparent early that reasonably distinct vegetation zonation paralleled the lake shore. There is a lowermost zone which is flooded annually and which primarily supports ephemeral vegetation. There is a second zone which was flooded once in 1969 when water level reached its maximum (Fig. 2) but has not been flooded since. Finally, there is the upland vegetation which has never been inundated but has been altered by man's activities. After this preliminary survey 50 permanent sites were established, 44 on Lake Sakakawea and 6 on the adjoining Lake Audubon. Since the water level in Lake Audubon does not fluctuate greatly, sites there could well provide data which would possibly show contrasting effects due to water level fluctuations of Lake Sakakawea. These sites were widely spaced around the perimeter of the lakes (Fig. 1). Sites were selected where some vegetation was growing or where we thought there was the potential of vegetation establishment. This, of course, precluded selecting sites along the steep eroded cliffs surrounding much of Lake Sakakawea. Most, but not all, of the sites were located in protected embayments where wave action is minimal. Use of a boat made it possible to establish many of our

sites at some distance from more heavily visited areas.

At each site two steel fence posts were driven into the ground to permanently mark the exact location. One post was planted well above the highest water mark, and the other was planted as far out in the water as we could wade. The sites were established at the time of high water level. The slope and aspect of each site was measured with a Brunton compass and recorded. Soil samples were collected from each site, and a photograph was taken of each site.

After we had established our study sites in 1971 we still had time to revisit 39 sites and analyze the vegetation. We stretched a steel tape between the two permanent markers, and using a 2 x 5 dm plot frame we analyzed vegetation within 30 plots evenly spaced along the tape. Coverage of each species was estimated and recorded according to a method described by Daubenmire (1959).

In the summer of 1972 the vegetation at each site was analyzed three times, once in June, once in July, and once in August. This was to obtain maximum coverage estimates of all the plants occurring at each site throughout the growing season. Soil samples were collected from each vegetation zone at nine different sites to compare certain soils characteristics from each zone.

<u>Laboratory Studies</u>. Using a Hellige-Truog combination soil testing kit we determined the readily available phosphorus, potassium, calcium, magnesium, sulfate, and chloride contents of the soil samples. We used a Beckman expandomatic pH meter to determine the pH on the soil paste, and the method of

Walkley and Black as modified by Walkley and by Smith and Weldon (Moodie et al. 1963) to determine the organic matter. Mechanical analyses were done using a modified Bouyoucos method (Moodie et al. 1963). Kjeldahl nitrogen determinations were done by the soils testing laboratory at South Dakota State University, Brookings. Species identifications were also verified in the herbarium.

From the coverage data obtained during the three visits at each site, we used the largest value for each species to calculate average coverage per plot along each transect. Total average coverage per plot was then the sum of the individual species coverages within each zone. Vegetation data from the upland zone which has never been inundated were kept separate from data collected along a zone flooded only once, in 1969. And these data were kept separate from those collected along the lowermost zone which is annually flooded. From these data, we also calculated frequency, the percentage of plots in which a species occurs within a zone at a given site. Constancy which was also calculated is the percentage occurrence of a species at all sites within a given vegetation zone.

RESULTS AND DISCUSSION

Soils. The Paleocene Tongue River formation of the Fort Union group (Leonard, 1930) underlies all of the area of our study. This formation was covered with a mantle of glacial ground moraine during the Kansas glaciation.

The soils of North Dakota are primarily pedocals, accumulating lime in the profiles (Rudd, 1951). In the dry western part of the state the soils are primarily Chestnuts, forming on both the glacial ground moraine, and exposed sedimentary deposits; but in many areas erosion is taking place so rapidly that the parent material is relatively unchanged. Consequently, the soils of western North Dakota are a mosaic of Chestnuts on the more level areas and regosols and lithosols on rapidly eroding sites. The descriptions that follow are based on Omodt *et al*. (1968) and Patterson *et al*. (1968). The primary Chestnut soils are the following:

1. Williams: forming on loam or clay-loam glacial till in areas of 1 - 8% slope. The Williams soils have about a 10 cm dark brown A horizon with a granular structure.
2. Morton: forming on medium textured soil weathered from Tertiary sedimentary deposits. The A horizon is up to 25 cm thick and is a dark brown with a silt loam texture.
3. Vebar: Forming on weathered sandstone of nearly level topography. These are well-drained soils with an A horizon of up to 23 cm of dark brown sandy loam with a weak crumb structure.
4. Agar: forming on loess with an A horizon of up to 15 cm of brown silt loam with a moderate granular structure.

Soils of the more rapidly eroding substrates are the following:

1. Zahl: forming on steeper slopes and hilltops of glacial till areas. The A horizon is up to 13 cm deep and is composed of dark brown loam with a moderately granular structure.
2. Bainville: regosols forming on steep slopes weathered from Tertiary beds. The A horizon is composed of 5-15 cm of granular silt.
3. Flasher: lithosols forming on resistant sandstone caps, most commonly with slopes of between 15 and 30%. The A horizon consists of 10 - 36 cm of dark brown loamy sand with a weak crumb structure.

Soils occupying only limited areas and occurring only in special situations in our study area are the following:

1. Tetonka: forming in poorly drained depressions on glacial till.
2. Renshaw: chernozems forming on gravelly glacial outwash.
3. Sioux: regosols forming on steeper gravelly glacial outwash.
4. Parshall: chestnuts forming on coarse-textured alluvium along stream terraces.
5. Farland: chestnut soils forming on wind blown eroded sandstone or medium-textured alluvium in nearly level areas.
6. Bowbells: chestnut soils forming on concave slopes in glacial till areas.
7. Oahe: chestnuts forming on glacial outwash that is level to undulating.

8. Lihen: chestnuts forming on coarse water deposited level plains.

The soil associations shown in Fig. 3 may contain many of these soil types, but the most predominant soil types in the association gives the association its name. With the names of the associations, Fig. 3 shows that along the eastern half of the north shore of the reservoir bordering the glacial till Williams soils predominate on level areas with Zahl soils on the steeper slopes. Further west where the reservoir contacts the bluffs of the former Missouri River the steeper Bainville soils replace the Williams to a degree and the Zahl soils become more abundant. South from New Town along the west side of the reservoir Bainville and Morton soils predominate; still farther south these soils are replaced by Flasher and Vebar soils. Along the Little Missouri River arm of the reservoir Bainville soil is most common among the badlands. The rest of the southeastern shore consists in various amounts Bainville, Zahl, Agar, and Williams soils with the soils of the steeper slopes gradually being replaced by those of the level land.

Since soil development is closely related to climate, vegetation and parent material, and since climate, upland vegetation and parent materials are quite uniform throughout the study region, the zonal soils which have developed also have been quite uniform. Variations which do occur in the soils have been the result of topography and some differing parent material, particularly in the vicinity of the Little Missouri River where rapid erosion has prevented development of mature soil profiles.

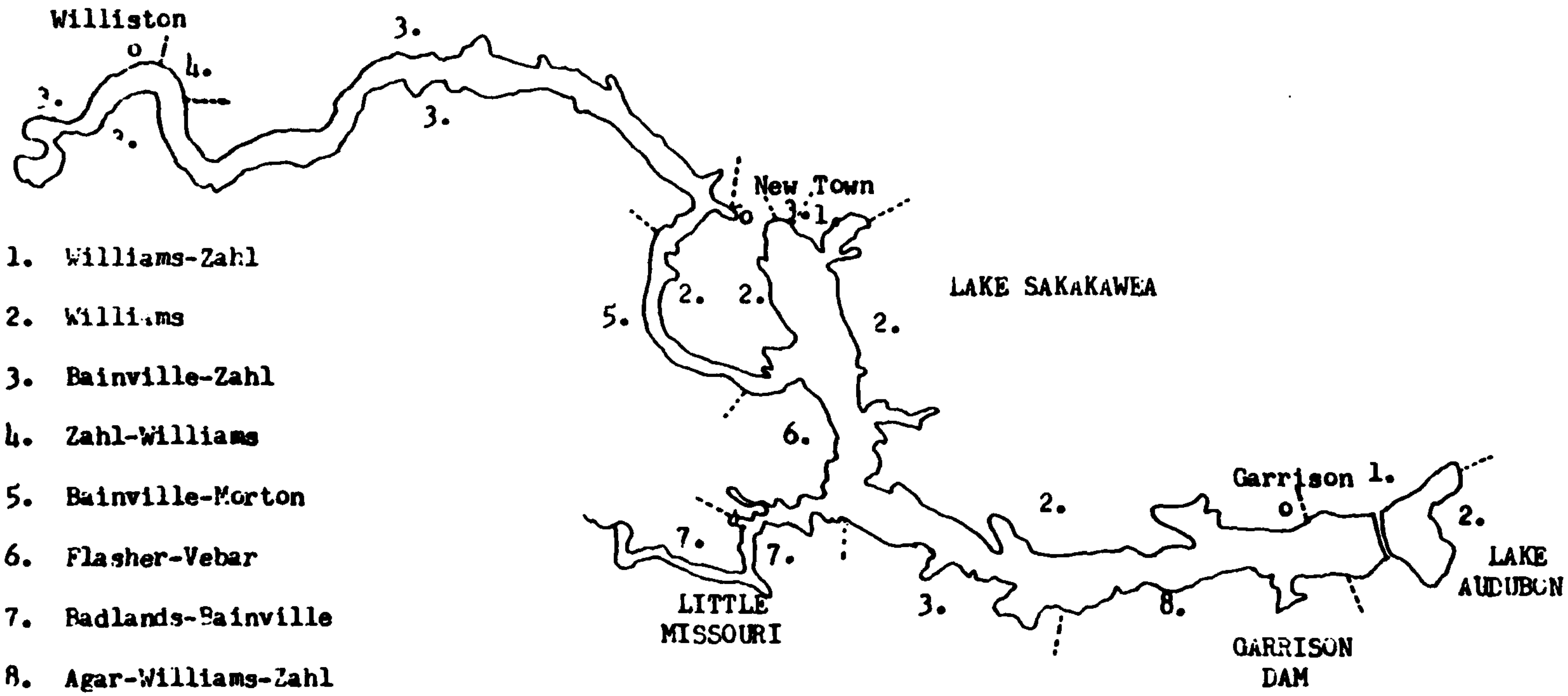

Fig. 3. Soil associations around Lake Sakakawea and Lake Audubon

The similarity of the results of our soils analyses also bear out the contention that the soils in the area are much alike. All but one of our soil textures contains the word loam in its type name. Of the 50 soil textural types, 27 were loam (Fig. 4). The results of the soil tests are found in Table 2. We found predictably high amounts of phosphorus although the range was from very low to very high. Magnesium ranged from very low to very high with the values tending to be high where the substrate was Tertiary sedimentary rock and low where the soil was forming on glacial till. Calcium ranged from high to very high with the great majority of the soils tested being very high. Potassium ranged from medium to very high, most soils were either high or very high. Chloride values were either very low or low with low being the more common value. Nitrogen and organic matter were low except for a few sites such as site number 12, where terraces have been built to collect silt and water making this a rich mesic site. Sulfate values ranged from very low to medium and were most commonly very low. The pH values of the soils were about what one might expect in soils forming under the process of calcification (Table 2).

To determine whether there was any conspicious erosion from the upland portion of our transects to the lowermost portion we sampled soils from the 3 zones of 9 sites. We determined particle size distribution and organic matter for each sample to learn whether the finer particles and/or organic matter were being eroded or transported from a higher zone to a lower zone. As shown in our data (Table 3) there are no trends in either the percentages of sand, silt or clay,

Figure 4. Results of mechanical analyses are shown on the soil textural triangle. The textural class of each soil sample for each site, 1 through 50, is indicated by the position of the number in the triangle.

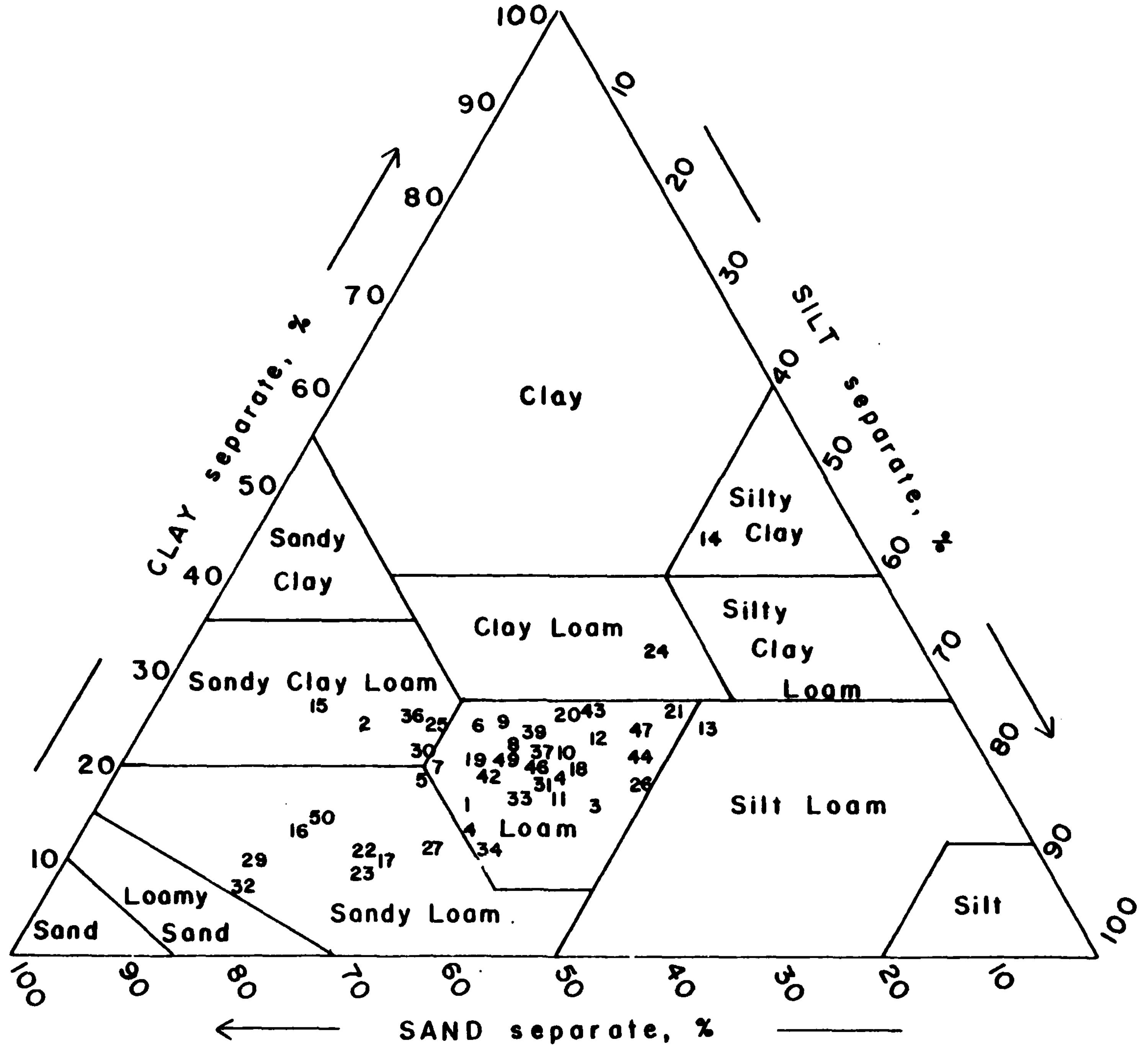
CLAY separate, %
SILT separate, %
SAND separate, %
Clay
Sandy Clay
Silty Clay
Clay Loam
Silty Clay Loam
Sandy Clay Loam
Loam
Silt Loam
Sandy Loam
Loamy Sand
Sand
Silt

Table 2. Soil characteristics of study sites.

Site	Mechanical Analyses				Nutrient Analyses ppm.[a]							% Organic	
Number	% Sand	% Silt	% Clay	Name	P	K	Ca	Mg	SO_4	Cl	% N[b]	Matter[c]	pH
1.	48	34	18	loam	25	120	3000	125	125	125	.296	.65	6.6
2.	55	22	23	sandy clay loam	25	80	3000	250	125	125	.196	.48	6.9
3.	47	28	15	loam	25	160	2000	125	125	125	.244	.14	6.8
4.	40	42	18	loam	100	160	3000	125	125	125	.233	.21	7.4
5.	53	29	18	sandy loam	12	120	3000	500	125	125	.185	.27	7.5
6.	45	30	24	loam	25	120	3000	500	125	125	.240	.22	7.5
7.	52	29	20	loam	38	160	3000	500	125	250	.212	.22	7.6
8.	43	36	21	loam	38	160	3000	500	125	125	.302	.22	7.1
9.	32	41	27	loam	62	160	2000	250	250	125	.251	.27	6.5
10.	40	39	21	loam	62	160	3000	500	125	125	.435	5.80	7.2
11.	42	43	16	loam	62	80	2000	250	125	125	.210	.27	6.4
12.	35	43	22	loam	62	160	3000	250	125	125	.693	1.33	7.0
13.	25	52	23	silt loam	62	160	2000	250	125	250	.306	.48	6.3
14.	13	43	43	silty clay loam	62	160	3000	500	125	250	.266	.12	7.8
15.	59	26	15	sandy loam	62	160	2000	250	125	125	.127	1.88	6.3
16.	65	22	13	sandy loam	38	160	3000	250	750	125	.176	.14	7.3
17.	61	27	12	sandy loam	62	160	3000	250	250	125	.149	.69	6.3

Table 2. Contd.

Site	Mechanical Analyses				Nutrient Analyses ppm.[a]							% Organic	
Number	% Sand	% Silt	% Clay	Name	P	K	Ca	Mg	SO_4	Cl	% N[b]	Matter[c]	pH
18.	39	40	21	loam	100	160	3000	125	125	125	.283	.14	6.7
19.	47	32	21	loam	38	160	3000	250	125	125	.178	.12	7.3
20.	40	34	26	loam	12	120	3000	500	125	125	.174	.18	7.5
21.	27	47	26	loam	12	160	3000	600	125	125	.170	.10	6.7
22.	62	28	10	sandy loam	62	160	3000	500	125	125	.172	.31	7.2
23.	62	28	10	sandy loam	38	160	3000	600	750	125	.136	.10	7.7
24.	25	43	32	clay loam	12	160	3000	600	125	125	.234	.10	7.7
25.	48	28	25	sandy clay loam	12	160	3000	600	125	125	.113	.14	7.1
26.	33	51	17	loam	100	160	3000	500	125	125	.251	.10	7.4
27.	31	56	13	silt loam	12	120	2000	600	250	250	.164	.10	8.5
28.	51	35	14	loam	62	160	2000	250	125	125	.336	-	6.2
29.	73	16	10	sandy loam	62	160	3000	250	125	125	.223	.05	6.5
30.	51	28	21	sandy clay loam	100	160	3000	400	125	125	.249	5.14	7.4
31.	41	40	20	loam	100	160	3000	1000	125	125	.274	.10	6.1
32.	75	18	7	sandy loam	12	160	3000	1000	125	125	.112	.05	7.5
33.	45	37	17	loam	100	12	3000	500	125	125	.278	.10	8.0
34.	52	41	[illegible]	loam	25	160	3000	1000	250	125	.136	[illegible]	7.8

Table 2. Contd.

Site	Mechanical Analyses				Nutrient analyses ppm.[a]							% Organic	
Number	% Sand	% Silt	% Clay	Name	P	K	Ca	Mg	SO_4	Cl	% N[b]	Matter[c]	pH
35.	25	51	24	silt loam	12	160	2000	1000	125	125	.204	-	6.6
36.	52	23	25	sandy clay loam	25	160	3000	1000	125	125	.128	.05	7.5
37.	41	38	21	loam	12	120	3000	1000	125	125	.077	.10	6.7
38.	33	53	14	silt loam	12	80	3000	1000	250	125	.064	.14	7.5
39.	40	29	31	sandy clay loam	25	160	3000	1000	250	125	.066	.14	6.0
40.	11	31	58	clay	12	120	3000	1500	125	125	.045	-	7.4
41.	48	35	17	loam	62	160	3000	1000	125	125	.204	-	6.1
42.	49	33	18	loam	62	125	1000	1000	125	125	.155	.10	7.2
43.	35	40	25	loam	38	120	3000	1000	125	125	.248	.10	7.3
44.	30	52	18	silt loam	62	160	2000	1000	125	125	.187	.10	6.7
45.	52	34	14	loam	62	80	3000	1000	750	125	.074	.05	6.4
46.	40	36	24	loam	62	160	3000	1000	250	125	.200	-	7.0
47.	30	46	24	loam	100	120	2000	1000	250	125	.359	.14	6.2
48.	20	53	28	silty clay loam	25	80	3000	1000	125	125	.032	-	7.5
49.	45	36	20	loam	100	160	3000	1000	125	125	.253	.05	7.5
50.	65	21	14	sandy loam	25	120	3000	1000	125	125	.157	.10	7.8

[a] These are maximum values based on results of Heltige soil tests.

[b] Determined by Kjeldahl method.

[c] Determined by a modified Walkley and Black method (Peech et al. 19[illegible]2)

Table 3. Soil characteristics of vegetation zones.

Site	Zone 1.				Zone 2.				Zone 3.			
Number	% Sand	% Silt	% Clay	% Organic Matter	% Sand	% Silt	% Clay	% Organic Matter	% Sand	% Silt	% Clay	% Organic Matter
11.	46	44	10	.18	41	44	15	.10	52	37	11	.05
		loam				loam				loam		
12.	37	49	15	.22	43	43	14	8.48	34	45	21	1.5[illegible]
		loam				loam				loam		
13.	38	47	15	1.03	21	58	21	.22	33	53	14	.14
		loam				silt loam				silt loam		
15.	74	13	13	.14	66	24	11	.05	63	26	11	1.88
		sandy loam				sandy loam				sandy loam		
16.	72	17	11	.14	49	38	13	.18		—		
		sandy loam				loam						
17.	66	22	12	7.88	52	35	14	.56	63	26	11	.10
		sandy loam				loam				sandy loam		
21.	40	52	13	.05	50	[illegible]	11	.22		—		
		silt loam				loam						
36.	23	46	31	.10	60	19	21	.05	66	22	12	.01
		clay loam				sandy clay loam				sandy loam		
42.	40	21	20	.01	59	23	18	.05	54	28	18	.21
		loam				sandy loam				sandy loam		

or organic matter from one zone to another. Nine sites is perhaps an inadequate sample, but still one might suspect a trend to appear in the results if erosion were removing finer particles and organic matter from the inundated zone and leaving behind coarser particles.

Lake Sakakawea Vegetation. The water management policies described in the Introduction have resulted in a type of vegetation zonation distinct from the zonation ordinarily associated with pond succession. We noted three vegetation zones around Lake Sakakawea. The first of these three zones (zone 1) is found on that part of the shoreline that is ordinarily inundated when the water comes up in the summer. This area lies between the 1840 and the 1849 (560-564 m.) foot contour lines (Fig. 2). Two distinct plant communities are found in
Curled Dock smartweed
this zone. The most common is a *Rumex crispus*-*Polygonum persicaria* annual weed community. On a typical site characterized by this community there are three overlapping sub-zones. Starting at the waters edge and moving up the shore these sub-zones consist of first a bare area, an area of increasing
Foxtail
Polygonum persicaria, and an area dominated by *Alopecurus*
Purslane Speedwell
aequalis and *Veronica peregrina*. These zones are not distinctly delimited, but rather they blend gradually into each other. *Rumex crispus* is scattered throughout the vegetation of Zone 1. As the water gradually inundates this zone most plants are killed. A small percentage of *Polygonum persicaria* survive this inundation by developing swollen nodes (for floatation and aeration), and by stem elongation. The disseminules of *Alopecurus aequalis* and *Veronica peregrina*

probably mature before inundation, accounting for their continuing presence. Rumex crispus appears to ripen upon inundation. The other community occurring on fewer sites of Zone 1 is an almost pure stand of Reed Canarygrass Phalaris arundinacea. This species appears to be spreading into this area from the zone above where it is more extensive. Western wheatgrass Agropyron smithii, Quackgrass Agropyron repens and Kent. Bluegrass Poa pratensis appear to be survivors in this area from an earlier upland community, and they along with the grasses Squirreltail grass Hordeum jubatum and Am. Sloughgrass Beckmania syzigachne all cover more than 1% of the area. In Table 4 the coverage, frequency, and constancy of all species are listed in order of decreasing coverage values. Each species is first listed in the zone in which it had the largest coverage. It may be seen in Table 4 that Smartweed Polygonum persicaria, which was found on 33 of the 38 sites investigated and which dominated 17 of these 38 sites, covered 15% of the total area (much more than any other plant). Phalaris arundinacea occurred on 6 of the 38 sites, was dominant on 4, and covered 6% of the area. On the four sites where it was dominant it had a remarkably high coverage value of 59%. Six sites were dominated by Rumex crispus, which covered 7% of the area, and two sites were dominated by Alkaligrass Puccinellia airoides which covered 4% of the total area. Eighty-one species were found in Zone 1 in 714 plots on 38 sites. The average cover of all species per plot was 61%. This figure was highest on the first analysis and declined on subsequent analyses as the water rose, flooding the zone and killing the plants.

Table 4. Percentage cover, frequency, and constancy of each species occurring in each zone of Lake Sakakawea and Lake Audubon.

	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
Species	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Polygonum persicaria	15	51	87	5.9	15	40	.03	2.0	5.0				.04	2.0	17	.08	3.0	17
Rumex crispus	7.6	27	79	3.8	19	60	.20	2.0	9.0				.94	11	50	.05	2.0	17
Alopecurus aequalis	6.7	27	50	2.7	9.4	30							.08	4.0	17			
Phalaris arundinacea	6.2	8.9	16	5.0	8.0	20	.51	2.0	9.0				1.1	9.0	66			
Beckmania syzigachne	2.0	.90	34	.46	2.0	10				.04	2.0	17	8.4	24	33	.53	5.0	17
Typha latifolia	.81	3.2	16										12	36	33			
Polygonum ramosissimum	.75	5.0	39	.18	3.1	20	.39	2.0	50									
Veronica peregrina	.58	5.9	21	.27	0.4	3.0												
Rorrippa islandica	.28	2.1	13	.24	2.0	17												
Echinochloa crus-galli	.17	1.2	9.0	.07	0.8	3.0	.02	1.0	5.0									
Scolochloa festucacea	.15	0.2	3.0							4.0	6.0	17	2.2	16	50			
Salix interior	.13	0.5	3.0															
Scirpus paludosis	.12	0.6	3.0							.05	1.0	3.0						
Lappula redowski	.08	2.4	5.0	.01	0.4	3.0												
Hackelia deflexa	.07	0.7	3.0	.06	0.4	3.0												
Potomageton sp.[a]	.06	0.4	5.0															

Table 4. Contd.

Species	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Eragrostis cilianensis	.05	0.1	3.0															
Ranunculus sceleratus	.03	1.4	3.0															
Collomia linearis	.03	0.3	5.0	.01	0.4	3.0							.27	2.0	17	.26	2.0	17
Capsella bursa-pastoris	.02	0.3	3.0	.01	0.4	3.0												
Salix amygdaloides	.02	0.1	3.0													.25	2.0	17
Prunus besseyi	.01	0.5	3.0	.01	0.4	3.0												
Salsola kali	.01	0.4	5.0	.01	0.4	3.0												
Festuca octoflora	+[b]	0.1	3.0															
Populus deltoides	+	0.1	3.0															
Hordeum jubatum	4.1	13	61	26	60	90	2.7	9.0	18	.05	1.0	16	18	34	50	2.0	12	33
Poa pratensis	1.4	4.9	26	13	30	63	4.2	15	45				6.8	15	50	7.3	20	50
Puccinellia airoides	4.5	15	58	6.9	47	63	.87	2.0	14							2.0	10	17
Cirsium arvense	.01	1.0	5.0	5.8	20	40	1.3	5.0	32				2.5	9.0	17	.48	3.0	17
Carex laeviconica	.26	2.2	16	5.5	8.7	13	.90	6.0	18	11	14	17	20	33	33	.64	3.0	17
Melilotus sp.	.01	0.4	5.0	3.9	7.5	13	1.3	6.0	23									
Poa palustris	.88	3.8	16	3.4	16	40	1.6	10	18				2.1	6.0	33			

Table 4. Contd.

	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
Species	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Carex brevior	.19	0.6	13	2.7	8.9	23	.24	1.0	9.0									
Lactuca scariola	.03	0.3	3.0	2.6	12	20	2.0	11	41				1.9	13	50	2.5	20	33
Potentilla norvegica	.47	5.4	37	2.4	13	60	.63	3.0	18									
Agropyron trachycaulum	.05	0.3	3.0	2.2	6.4	17	1.9	3.0	5.0				.27	2.0	17	2.0	13	33
Sonchus arvensis				1.6	5.1	20	1.4	15	18				2.2	9.0	33			
Xanthium strumarium	.12	0.6	3.0	1.5	6.3	7.0												
Artemisia dracunculus				1.2	4.8	13	.68	5.0	18									
Brassica nigra	.13	2.6	18	.96	0.7	13	.51	1.0	5.0									
Eleochris ovata	.03	0.4	5.0	.94	4.8	13	.70	2.0	5.0	1.0	1.0	17	.90	4.0	17	12	26	17
Helianthus annuus	.02	0.3	5.0	.86	5.2	17												
Aster hesperius	.05	0.3	3.0	.85	3.6	17	.11	1.0	9.0				11	32	100	.57	6.0	33
Rumex occidentalis	.05	0.4	5.0	.76	3.9	10	.22	1.0	5.0									
Fraxinus pennsylvanica	+	0.1	3.0	.71	4.0	3.0												
Solidago rigida				.46	1.2	7.0												
Bromus japonicus				.44	1.6	3.0												
Ambrosia trifida	+	0.1	3.0	.38	1.6	7.0	.09	1.0	5.0							1.2	5.0	17
Melilotus alba				.35	1.2	3.0												

Table 4. Contd.

Species	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Lepidium densiflorum	.04	0.9	8.0	.33	3.6	13										.05	2.0	17
Stellaria crassifolia	.21	2.0	18	.28	3.5	13										2.0	16	17
Eleocharis palustris	.02	0.8	5.0	.28	0.8	7.0				4.2	12	17	.35	5.0	17			
Rumex maritimus				.27	0.4	3.0				1.0	2.0	17				.49	3.0	17
Thalaspi arvensis	.02	0.1	3.0	.25	2.0	3.0												
Elymus canadensis				.20	1.7	10												
Hydrophyllum virginianum	+	0.2	3.0	.15	2.0	10												
Plantago eriopode	.04	0.3	3.0	.14	0.9	3.0												
Beggar's tick, Stick-tight Bidens vulgata	.04	0.8	8.0	.13	1.2	7.0							.08	4.0	33			
Carex lanuginosa	.02	0.9	3.0	.13	1.2	3.0												
Eriperon lonchophyllus				.10	0.3	3.0	.01	1.0	5.0									
Polygonum coccineum				.10	0.8	3.0				7.5	17	33	5.5	16	33			
Polygonum erectum	.02	0.7	5.0	.07	0.8	7.0												
Scirpus atrovirens	.02	0.1	3.0	.07	0.8	3.0												
Menthe arvensis	+	0.1	3.0	.06	0.4	3.0				.22	1.0	17	.82	5.0	17			
Atriplex patula				.06	0.4	3.0							.04	22	17	1.4	10	17
Artemisia biennis				.06	0.4	3.0												

Table 4. Contd.

	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
Species	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Camelina microcarpa				.06	0.4	3.0												
Descurainia sophia				.06	0.4	3.0												
Juncus balticus				.06	0.4	3.0												
Plantago major				.06	0.4	3.0												
Chenopodium album	.02	1.0	11	.04	0.6	7.0												
Artemisia cana				.02	0.8	3.0												
Carex eleocharis	.01	0.3	3.0	.01	0.4	3.0										5.2	23	17
Cirsium undulatum				.01	0.4	3.0												
Cornus stolonifera				.01	0.4	3.0												
Kochia scoparia	.01	0.3	3.0	.01	0.4	3.0												
Plantago purshii				.01	0.4	3.0										2.7	10	17
Setaria lutescens				.01	0.4	3.0												
Thalictrum sp.				.01	0.4	3.0												
Ulmus americana				.01	0.4	3.0												
Agropyron smithii	1.7	4.5	24	20	47	73	38	61	73				2.3	9.0	33	5.3	23	17
Symphoricarpus occidentalis				.75	8.1	23	10	15	27									
Agropyron cristatum				1.8	5.1	17	10	11	14							.25	5.0	33

Table 4. Contd.

	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
Species	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Agropyron repens	2.5	7.9	26	7.3	22	57	8.0	26	50				2.6	5.0	33	.92	5.0	33
Bromus inermis	.02	0.1	3.0	2.1	8.5	23	7.8	12	18				3.1	5.0	17	30	41	33
Stipa comata				.08	1.2	7.0	7.0	9.0	18									
Carex filifolia							4.6	9.0	9.0									
Lactuca pulchella	.33	3.4	21	1.7	12	43	4.2	15	5.0				.68	2.0	17	2.1	13	33
Aster ericoides				.32	2.0	17	3.9	17	27							3.5	13	33
Stipa viridula				.21	0.8	3.0	3.9	15	23							.08	3.0	17
Rosa arkansana	.01	1.0	5.0	.76	4.8	7.0	3.2	12	27							.25	2.0	17
Agrostis hiemalis	+	0.1	3.0	1.7	5.5	23	2.4	13	27									
Tragopogon dubius				.54	5.2	20	1.9	8.0	36							2.0	16	50
Solidago missouriensis							1.7	4.0	9.0									
Melilotus officinalis	.10	0.4	5.0	.44	3.6	13	1.6	6.0	18				7.6	14	50	26	38	66
Convolvulus arvensis	.02	0.1	3.0	.15	2.0	13	1.5	5.0	23				5.4	4.0	33	.62	2.0	17
Artemisia ludoviciannna				.10	0.7	7.0	1.4	5.0	14									
Gaura coccinea							1.4	2.0	5.0							.05	2.0	17
Artemisia frigida				.39	3.2	10	1.3	7.0	32							.24	15	17

Table 4. Contd.

	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
Species	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Koeleria cristata				.21	0.8	3.0	1.3	6.0	9.0							.94	6.0	9.0
Poa interior	+	0.1	3.0	.07	0.8	7.0	1.2	1.0	9.0									
Conyza canadense				.21	0.8	7.0	1.2	5.0	23							.86	10	17
Psoralia argophylla							1.2	5.0	14									
Ribes americanum							1.2	2.0	5.0									
Ratibida columnifera				.82	6.5	20	1.0	5.0	18							.05	2.0	17
Vicia americana				.13	1.3	7.0	1.0	8.0	18							.52	13	50
Achillia millefolium				.12	1.2	3.0	.96	10	27				.27	2.0	17	2.2	10	17
Urtica dioica				.31	2.4	10	.78	1.0	5.0									
Convolvulus sepium				.01	0.4	3.0	.70	3.0	9.0									
Aster oblongifolius							.39	1.0	5.0									
Ambrosia psilostachya				.08	1.2	10	.35	2.0	9.0									
Anemone canadensis	.02	0.1	3.0	.23	1.6	10	.28	2.0	14				.28	1.0	17			
Sysimbrium altissimum	.05	5.3	11	.03	1.2	10	.23	1.0	9.0									
Bouteloua gracilis							.22	3.0	14									
Oenothera biennis				.18	1.6	7.0	.22	1.0	5.0									
Apocynum canabinum							.20	6.0	5.0							.04	2.0	17

Table 4. Contd.

	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
Species	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Bouteloua curtipendula							.17	1.0	5.0									
Calamovilfa longifolia							.10	1.0	5.0									
Oxalis stricta							.10	1.0	5.0									
Plantago eriopode							.09	1.0	5.0									
Verbena bracteata	.05	1.0	5.0	.01	0.4	3.0	.09	1.0	5.0									
Iva xanthifolium				.06	0.8	3.0	.09	1.0	9.0									
Monardo fistulosa				.06	0.4	3.0	.09	1.0	5.0									
Lactuca biennis							.09	1.0	5.0									
Taraxacum officinale				.05	0.7	7.0	.08	1.0	5.0				1.3	1.0	17	2.2	13	17
Herecleum lanatum							.08	1.0	5.0				.28	2.0	17			
Cirsium flodmani							.02	1.0	5.0									
Epilobium adenocaulon							.02	1.0	5.0				1.3	9.0	50	2.8	5.0	33
Senicio sp.							.01	1.0	5.0				.04	2.0	17			
Polygala alba							.01	1.0	5.0									
Potamogeton gramineus										3.7	17	50	1.8	2.0	17			
Chara sp.										3.0	14	33						
Ranunculus flabellaris										.05	1.0	17						

Table 4. Contd.

	Lake Sakakawea									Lake Audubon								
	Zone 1.			Zone 2.			Zone 3.			Zone 1.			Zone 2.			Zone 3.		
Species	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.	CV.	FR.	CN.
Typha angustifolia													10	16	17			
Alisma plantago-aquatica										.57	1.0	17	3.3	26	17			
Lemna minor										1.4	12	17	1.7	13	17			
Medicago sativa													1.9	9.0	33	9.6	28	17
Linum rigidum																.30	3.0	17
Amorpha nana																.25	2.0	17

The second vegetation zone occurs on that part of the shoreline between the elevations of 1849 and 1850.5 feet (563.6-564 m) above mean sea level and was inundated only once in the summer of 1969. The vegetation growing in this area was killed at that time, and the vegetation growing in this area in 1971 and 1972 was the result of two and three years development respectively. Compared to Zone 1 which had 81 species in 714 plots Zone 2 contained 103 species in 253 plots, and also had a larger average cover per plot of 153% compared to 61% for Zone 1. Cover values greater than 100% can occur primarily becuase of superimposed plant canopies of different species, and also because of different plants attaining maximum vegetative development at different times during the season. In Zone 2 there are also two distinct communities. The same *Phalaris arundinacea* community occurring in Zone 1 reaches its maximum development in Zone 2. Where *Phalaris arundinacea* was present at three sites it dominated both Zones 1 and 2. *Phalaris arundinacea* covered only 5% of the total area, but had a high coverage value where it did occur. The most common plant community in Zone 2 is an *Agropyron smithii*-*Hordeum jubatum* weed community. *Hordeum jubatum* covered 26% of the total area, was found on 21 of the 30 sites, was dominant on 12 sites, and was an important component of 7 more. *Agropyron smithii* covered 20% of the total area, was found on 21 of the 30 sites, was dominant on 7 of these sites, and was an important vegetative component in 6 additional sites. *Poa pratensis* covered 13% of the area, was found on 19 of the 30 sites, was dominant in 4 and was an important component of

6 sites. Puccinellia airoides was found on 19 sites, and was dominant on 3. Other plants dominating at least one site along with their average cover in Zone 2 were the following: Agropyron repens 7%, Cirsium arvense 6%, Agrostis hiemalis 2%, Carex laeviconica 5%, Poa palustris 3%, Polygonum persicaria 6%, Bromus inermis 2%, Helianthus annus 1%, and Melilotus sp. 4%. Other species with coverage exceeding 1% were the following: Agropyron trachycaulum 2%, Artemisia dracunculus 1%, Lactuca pulchella 2%, Carex brevior 3%, Alopecurus aequalis 3%, and Agropyron cristatum 2%.

The third vegetation zone is found above the highest water line. In this zone there is a sub-zone of lush vegetation next to the water line where the plants receive extra moisture from the lake and increased nutrients from decaying debris deposited by water. About one third of the sites in Zone 3 were vegetated by relatively undisturbed native grassland which Küchler (1964) refers to as the Agropyron-Stipa type. Weaver (1942) found Agropyron smithii to be a very strong competitor for moisture. We found Agropyron smithii increased near the water's edge.

There are several plant communities found in Zone 3. That community occurring on the relatively undisturbed sites is an Agropyron smithii-Stipa comata plant community. The dominant plants of this community are Agropyron smithii which covered 38% of the total area, was dominant on 11 of the 22 sites, and was found on practically all of the sites whether characterized by this plant community or not. Stipa comata covered 7% of the total area. Other important species were

Symphoricarpos occidentalis covering 10% of the area and characteristically growing in clones dotting the landscape, Carex filifolia 5%, Stipa viridula 4%, Psoralia argophylla 1%, Rosa arkansana 3%, Koeleria cristata 1%, Gaura coccinea 1%. All these are components of the native vegetation. Also present on two sites was a community consisting of almost 100% Agropyron cristatum which we believe was seeded in a field about to be abandoned as the reservoir water level rose. Agropyron cristatum covered 10% of the total area with most of the coverage being on these two sites. Bromus inermis formed a similar closed community on another site; this species covered 8% of the total area in Zone 3. Areas disturbed by farming or overgrazing and not reseeded as the water level in the reservoir rose were dominated by a weedy community we call the Agropyron repens-Poa pratensis community. This community is composed of numerous species. In addition to Agropyron repens with a total coverage value of 8% and Poa pratensis with a coverage value of 4% other conspicuous species and their coverage values are as follows: Convolvulus arvensis 2%, Lactuca pulchella 4%, Agrostis hiemalis 2%, Aster ericoides 4%, Conyza canadensis 1%, Lactuca scariola 2%. The Phalaris arundinacea associes also extends into this zone. Interestingly Zone 3 had exactly the same average vegetative cover, 153%, as that of Zone 2, but there is a difference in the vegetation between Zone 2 and Zone 3. Zone 3 has more dense vegetation but with little vertical stratification. Zone 2 vegetation is characterized by at least 2 distinct layers with one superimposed over the other.

Lake Audubon vegetation. The vegetation on the control sites on Lake Audubon is also characterized by three zones, though

these zones do not correspond exactly with the zones produced by the water fluctuation in Lake Sakakawea. The zones around Lake Audubon are the following: Zone 1, the open water zone, Zone 2, a narrow fringe of lush green emergent aquatic vegetation, and Zone 3, an upland zone corresponding to the Zone 3 of Lake Sakakawea.

Zone 1 of the control lake was almost devoid of vegetation, containing only some representatives of Potamogeton gramineus and Chara sp. except for one site above Lake Audubon where there was apparently extensive eutrophication before the dams were built and exhibited a mosaic of aquatic emergent vegetationtion such as Polygonum coccineum and Eleocharis palustris, and Scolochloa festucacea. Beard (1973) reported that winter draw-down of a lake severely retarded development of aquatic vegetation, but as there is essentially no winter draw-down in Lake Audubon, this cannot be a factor. Aquatic vegetation is also essentially at our sites around Lake Sakakawea but there the draw-down is considerable. We observed appreciable stands of Potomogeton sp. only in one bay at the Wolf Creek Game Management Area, Lake Sakakawea, although thin patches were occasionally observed on other sites. Large numbers of carp on both lakes, and an algal bloom on Lake Audubon were noted during both summers of our study.

Zone 2 on Lake Audubon is generally characterized by a Typha latifolia-Carex laeviconica emergent aquatic community, but this was frequently invaded by species characteristic of the upland vegetation. Important species found in this zone were the dominants, Typha latifolia which covered 12% of the area, the Carex laeviconica which covered 20% of the area.

Other important species and their coverage values were Beckmania syzigachne 8%, Polygonum coccineum 5%, Hordeum jubatum 18%, extensive on one bull-dozed site, Scholocloa festucacea 2%, Alisma plantago 3%, Typha angustifolia 10%, Phalaris arundinacea 1% and several other species more characteristic of the upper zone (Table 4).

Zone 3 around Lake Audubon is somewhat similar to Zone 3 around Lake Sakakawea. But because of differences in water level fluctuations and wave action primarily, similarities between Lake Audubon Zones 1 and 2 and Lake Sakakawea Zones 1 and 2 are considerably less. No grazing is now permitted around Lake Audubon at least in the areas where our sites are located, but all of the grasslands on the steeper rockier ground moraine appear to have been farmed or overgrazed at one time. One site was dominated by an apparently seeded Bromus inermis community, while most of the rest were dominated by Melilotus officinalis. The important species found here with their corresponding coverages are as follows: Hordeum jubatum 2%, Bromus inermis 30%, Melilotus officinalis 26%, Lactuca scariola 2%, Poa pratensis 7%, Agropyron smithii 5%, and Achillea millefolium 2%.

Succession from 1971 to 1972. During the summer of 1971 we had time to analyze the vegetation only at 29 sites and those in August. Thus, to compare our 1971 and 1972 data we examined only data from the same 29 sites on Lake Sakakawea. In Zone 1 there were significant changes in coverage of several important species. Phalaris arundinacea increased its coverage from 1% to 4%, Hordeum jubatum increased from 2% to 5%, Polygonum persicaria decreased from 11% to 2%, and Polygonum ramosissimum decreased

from 1% to .1%. Possibly the increase in Phalaris is part of a general trend of increase in emergent aquatics. We noted and we photographed an increase in Typha latifolia between 1971 and 1972 but too little of this species occurred in our plots to confirm the change. The decrease in the two Polygonums may have been the result of a more rapid and early rise in the water level in 1972 than in 1971. (See Fig. 2). This rapid rise probably drowned the young seedlings before they could become fully established.

In Zone 2 Polygonum persicaria also decreased, Rumex crispus increased from 1% to 3%, Hordeum jubatum increased from 6% to 8%, Poa pratensis increased from 2% to 4%, while Agropyron repens declined slightly. The most significant change in the vegetation was the increase in coverage of Agropyron smithii, from 2% to 14% over this one year period. Of course the cover of different species fluctuates from year to year and this dramatic increase in Agropyron smithii may not indicate a long term trend. Certainly one year is not long enough for us to make long range predictions from our data, but it will be very interesting to follow these trends for several years.

In Zone 3 Agropyron smithii increased from 13% to 27%, Bromus inermis increased from 1% to 6%, Symphoricarpos increased from 7% to 11%, Agropyron cristatum increased from 9% to 11%, and Stipa viridula increased from .5% to 2%. Stipa comata declined from 6% to 4%. Again the most significant change was in the percent cover of Agropyron smithii, which almost doubled from 1971 to 1972. Both years of our study were "high" moisture years and according to Weaver (1942) Agropyron smithii is a very

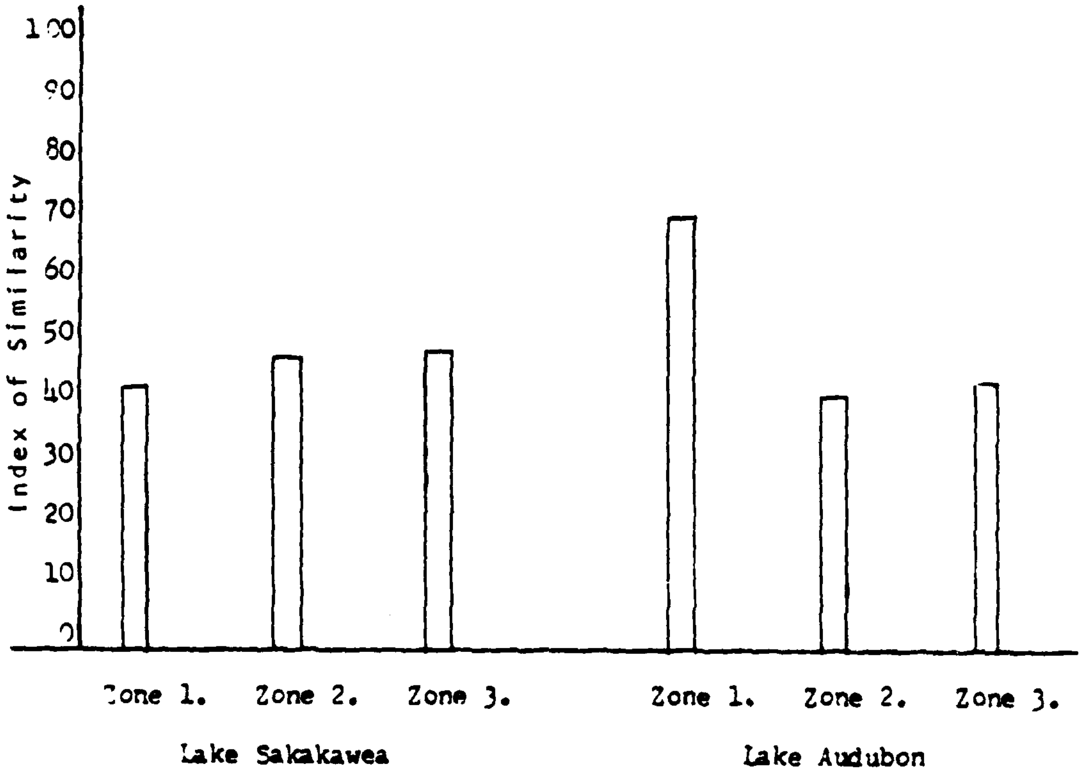

Fig. 5. Index of similarity values calculated using Jaccard's Index to compare 1971 and 1972 vegetation data for the three vegetation zones of Lake Sakakawea and Lake Audubon.

strong competitor in more mesic habitats. Two years of data tend to indicate that the seral Agropyron cristatum and the Bromus inermis communities are not being replaced by native grassland, even though in most places where they are found the original disturbance is not operative.

Using Jaccard's index of similarity (Oosting, 1956) we compared coverage for each of the zones between the two years. The data are presented in Fig. 5. The expression used to measure similarity (I.S.) is the following:

$$\text{I.S.} = \frac{2W}{a + b} \times 100$$

where

W = Sum of the lower coverage values for all species shared in the particular zone between 1971 and 1972.

a = Sum of all the coverage values of species in a particular zone in 1971.

b = Sum of all the coverage values of species in a particular zone in 1972.

The highest degree of similarity was found in Zone 1 on Lake Audubon. This is the result of very little vegetation found in Zone 1 except on one site dominated by emergent aquatic perennials, and very little change in the vegetation from 1971 to 1972. The reason for the low index of similarity in Zone 1 on Lake Sakakawea is different water management practice that affected the survival of Polygonum persicaria and other species. We cannot explain the slightly higher index of similarity in Zones 1 and 2 in Lake Sakakawea than in Lake Audubon, though we did sample a larger area on Lake Sakakawea and vegetation of Zone 3 on Lake Audubon was probably more disturbed. But in any

event there are small differences in similarity indexes in all but Zone 1 of Lake Audubon from 1971 to 1972.

Diversity. We are interested in plant species diversity and its meaning, particularly with regard to changes in diversity resulting from man's influence on the vegetation around Lake Sakakawea. Theoretically greater diversity is associated with greater stability of ecosystems, and we know that overall biotic diversity increases with successional development of an ecosystem. For vegetation this increase occurs up to a point and is limited by such things as floristic richness of the plant community, and competitive capacity of the individual species present. In some cases plant species diversity increases during succession, then decreases (Margalef, 1968). Natural selection acts to increase diversity and stability through time while man, almost invariably acts by increasing production to decrease the diversity, and therefore by the stability of the ecosystem (Odum, 1967).

The coverage data from our vegetational analyses make it possible to rank our plant species in decreasing order of the total area covered by each species. Plotted in this manner dominance-diversity curves for each zone are shown in Fig. 6. The species are arranged in sequence from the highest to the lowest coverage on semi-logarithmic graph paper. All three curves approximate sigmoid curves with some modification. In Zone 1 the upper half of the curve (Fig. 6) could also have been approximated by a geometric series. This is not unexpected in view of the rigorous environmental conditions in Zone 1, though there are numerous species of only intermediate importance and few of little importance, giving the overall sigmoid shape

to the dominance-diversity curve. Zone 2 curve is interesting in that dominance is less pronounced, with most species attaining an intermediate importance value. As a result the slope of the curve for Zone 2 is less steep along most of its length. In Zone 3 there is a well defined dominant group of plants, a large number of plants of intermediate importance, and a fairly large number of plants of much less importance.

To calculate diversity we used the Shannon-Wiener diversity index. Borrowed from information theory it provides, in bits of information, the mean diversity for the biotic community or a part thereof. The index is:

$$\overline{D} = (\sum_{i=1}^{m} \frac{n_i}{N} \text{ Log } 2 \frac{n_i}{N}$$

where n_i is the importance (coverage) value of the i^{th} species, m is the number of species, and N is the total importance (coverage) value for the community. This index takes into account the 2 factors which influence diversity: the number of species and the evenness of distribution of the importance values among the species. We calculated the diversity of equal areas, 172 plots, from each vegetation zone. The results are given in Table 5. The diversity in Zone 1 is low due to a paucity of species and the dominance by a few species. The diversity in Zone 3 is almost as high as the diversity in Zone 2 in spite of a lower number of species because here there is a larger number of species of intermediate importance. Our Zone 1 is a low diversity ephemeral plant community which must become reestablished each year after it has been inundated by rising water level of the lake.

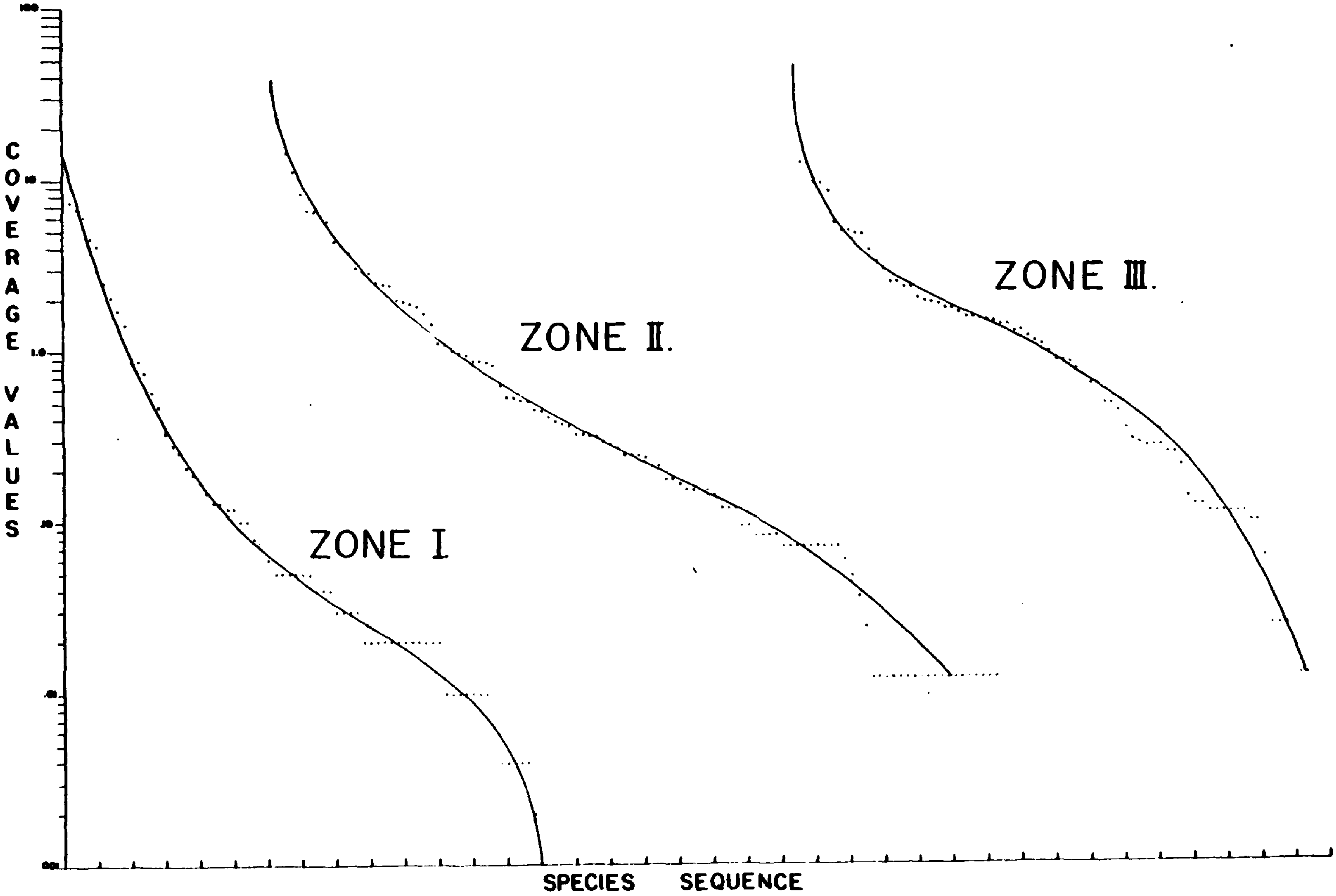

Fig. 6. Dominance-diversity curves for plant species in the three vegetation zones of Lake Sakakawea.

Table 5. A comparison of total species, total cover and mean diversity calculated from 172 plots in each zone.

	Zone 1.	Zone 2.	Zone 3.
Diversity	3.75	4.73	4.68
Total Cover	70.29	187.96	153.24
Total Species	43	94	76

Regression Analyses. Because of the complex nature of both the vegetation along Lake Sakakawea shoreline and the numerous environmental factors which influence that vegetation, some of our data were subjected to multiple regression analyses. Three soils characteristics, percent nitrogen, percent organic matter, and percent silt + clay as well as one topographic feature, degree slope were used as four independent variables in the regression. The dependent variable was plant species coverage.

In the Analysis of Variance for the Regression, an F value is calculated by dividing the sum of the squares attributable to regression by the mean squares. This value was not significant for those species checked in Zone 1. No one independent variable is consistently high or low in its influence on the dependent variable, vegetation cover. The same is true of Zone 2. All the species mentioned below which were affected by soils characteristics are in Zone 3.

To obtain some idea of the influence of the individual independent soil variables on vegetation cover we computed at-value (regression coefficient/std. error of the coefficient) for each variable. In Zone 3 *Agropyron smithii* was close to significantly influenced by soil organic matter. *Symphoricarpos occidentalis* was highly influenced by slope and organic matter. *Lactuca pulchella* was controlled by all three soil variables. *Poa pratensis* was controlled by the per cent of nitrogen. Since there was considerable influence of soil factors on the 10 most important species of Zone 3, we continued the regression analysis on the second group of 10 important species of Zone 3. Of the second ten only *Tragopogon dubius* was strongly controlled by

slope. No other soil factors were significant on any other species of this group.

The primary value of the multiple regression analyses was in indicating to us that of the soil factors tested only a limited number of significant regressions were obtained. This is important because it tends to reinforce what we think about two environmental factors which are less easy to quantify, namely water level fluctuations and wave action. One can tell that water level fluctuations and wave action both have significant influence on the vegetation. But obtaining accurate quantitative data on these variables is quite difficult. Experimental plantings this summer will help in providing more information on both of these factors.

The future of the shoreline vegetation. The shoreline of a man-made fluctuating water level reservoir presents a difficult environment for the establishment of vegetation. Factors which prevent vegetation establishment or destroy vegetation are mainly water level fluctuation, wave action, cattle grazing, erosion and carp activity which both destroys submerged aquatic species and adds to the turbidity of the water. These factors form a complex which in various combinations can destroy any vegetation completely, can retard vegetation development or can maintain a particular stage of succession.

On the open lake wave action is very effective in reworking the shoreline. Steps or terraces are formed by the material above the water which was cut away and deposited below the water line or moved for considerable distance along the shore (Akimov, 1959;

Pearsall, 1917). Where wave action is strong, waves erode away the bases of the shore creating an unstable slope, and large portions of the substrate slump, slip, or cave into the reservoir. Conditions are so unstable that almost no plants can exist in these areas.

The shoreline is also reworked during the winter by ice. We were unable to visit the lake during the winter months to observe the action of the ice, but observations of ice action on Lewis and Clark Lake, a smaller reservoir downstream, indicates this action is very effective. If the water level is lowered during the winter months the ice action is probably negligible along that portion of the shore which concerns us most in this study. Erosion along the shoreline is probably the result primarily of wave action. There is some minimal erosion of the bared substrate from rain and wind.

There is silt deposition and delta formation at the head of the reservoir and wherever tributaries enter the lake. Since Lake Sakakawea lies on a nearly level glacial ground moraine plain with a deranged drainage pattern there are few tributaries. The only significant tributary is the Little Missouri River. It drains the rapidly eroding substrate of the North Dakota 'badlands' and deposits a considerable load of silt and clay. We measured 30 cm of deposition on one mud-flat in one year! Around the perimeter of the lake deposition occurs as the material eroded away by wave action is built up into a shelf at the base of the cliffs or is carried along the shore by littoral currents and deposited at some distance from

the origin possibly across an inlet cutting it off from the main lake and shortening the shoreline. It should be remembered though that erosion of headlands and deposition in embayments is a normal geomorphologic feature of young lakes whether or not water level fluctuates significantly.

As the water level fluctuates the vegetation is alternately flooded and desiccated. It is well established (Conway, 1940) that the drop in oxygen concentration accompanying flooding is fatal to many species. Different species can tolerate varying amounts of flooding. Only species with special adaptations for root aeration can survive long periods of flooding. Most plants, particularly if they are well established can withstand desiccation much more easily than flooding. Submerged aquatics are killed by prolonged desiccation, even during their period of dormancy (Beard, 1973).

Grazing cattle around the reservoir is another factor working against vegetation establishment near the shoreline. Cattle often spend considerable time near and in the water, damaging the vegetation by both grazing and trampling. These activities add to the erosion problem.

We frequently observed carp working in the very shallow quiet places where plants might easily become established. Robel (1961) found that carp had little effect on emergent aquatics, but we feel that carp probably destroy our more ephemeral <u>Polygonum persicaria</u>-<u>Rumex crispus</u> weed community, though we do not have data to substantiate this.

Most of the lake is very transparent. Turbidity is high along the rapidly eroding points on windy days, but since most of our terrestrial species get established on the exposed shoreline when the water is down turbidity is probably not important to these species.

Along the upper reaches of the reservoir there is much dead timber floating in the water. This deadwood has two effects: (1) the mechanical rubbing action of this wood can destroy vegetation along the shore and logs deposited on the shore can cover soil and prevent plant growth: (2) this same deposited wood holds moisture, breaks the action of the waves, and collects silt deposits, all of which can promote plant growth. In fact, in the older Fort Peck Reservoir upstream of Lake Sakakawea dead wood deposited along the shores has nearly all been buried by silt and clay deposits.

In spite of these adverse environmental factors there is some vegetation growing along the shore around the reservoir. If a species is to survive on the bare apron of substrate between high water and low water levels it must be pre-adapted to withstand both flooding and desiccation posed by the new environment as well as the timing of water level fluctuations in relation to its own phenological requirements. It obviously must also be ecologically adapted to the climate of the region in which it appears. A search for plants thus adapted to both the climate of our study region and the peculiar habitat conditions along the lake should begin with the ecotypes found in this region. One value of the study thus far has been to learn which species appear capable of surviving, and expanding

their areas, on this lake shore. From what we have learned we plan to expand the study to "help" succession along in areas where, for some reason(s), plants have not yet become established. Agropyron smithii is one such species which is increasing near the water, and survives in water for a time, and has been shown experimentally to be capable of growing through soil deposits 30 cm thick (Mueller, 1941). It might survive on mud flats where silt deposition is a limiting factor for many other species. We have observed it on mudflats where it had been inundated, sent up a vertical rhizome, and grew new leaves above the water level. We also are cautiously optimistic about certain other species---Phalaris arundinacea, Typha latifolia, Phragmites communis and others---all mentioned above as possible plants which might remain permanently along the shoreline. So much depends on the magnitude and timing of water level fluctuations.

The water level of Lake Sakakawea is controlled primarily by climate and available runoff (Benson, 1968). Vegetation development could be enhanced by reducing the magnitude of the water level fluctuations, and by maintaining the water at a low level. After a period of time, perhaps two years, the water level could again be raised and flood the established vegetation. This practice would kill much of the vegetation but would also provide the needed spawning habitat for certain species of fish. Also, a sub-impoundment of one of the shallow bays with a pumping station to create the desirable water level would enable one to experimentally determine the effect of water management policies on the vegetation, and also therefore on fish spawning.

This study has answered far fewer questions than it has raised. Understanding of an ecological problem most often includes long range solutions for which many would like an immediate solution. Nature works in rather deliberate ways, and ecological problems simply seldom have short-term answers. Certainly, ecological problems have no simple solutions, because the interactions of biological forms and their environment (ecology) are extremely complex. We have learned quite a lot about shoreline vegetation on huge fluctuating water-level reservoirs of the upper Missouri River Basin, and we also know that what we have learned about this vegetation is keyed directly to the water-management practices during at least 1971-1972 and perhaps before 1971. Should the water management practices change significantly in 1973 and beyond, there would be direct effect on the vegetation. The shoreline vegetation around this kind of a reservoir is unique in that it adjusts to the natural forces of nature, and at the same time is forced to adjust to man-imposed forces, primarily those accompanying changing water levels. Should it be possible for the timing of water fluctuations to coincide with the times best suited to do the least damage to shoreline vegetation, and should be be possible for water level fluctuations to be minimized to afford the greatest survival of shoreline vegetation, we would be more than cautiously optimistic about continued vegetational succession. In the meantime we can work toward fuller understanding of reaction of vegetation to the current water management practices, and attempt to establish vegetation in areas where it does not now occur. Continued work in this area will give us the necessary background to honestly know whether vegetation can become

permanent and widespread, whether ephemeral vegetation is the only answer, or whether there is any "real" answer to this complex problem. But we know that only real data can provide the understanding necessary on which to make predictions.

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8